

Cognitive Techniques for Finding Spectrum for Public Safety Services

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ABSTRACT

Public safety and security (PSS) communications involve a unique application of a set of principles, a combination of technologies, and integration of processes to provide assured communications support for deployed emergency responders. Among other things, interoperability, reliability and scalability are key requirements for such systems. This paper discusses possible alternatives to enhance PSS communication network capabilities by implementing dynamic spectrum access. Possibilities for dynamically acquiring additional spectrum for PSS systems are discussed. A set of techniques introduced in the cognitive radio domain is discussed and their potential value in the PSS context is evaluated. The issue of using free spectrum spaces is particularly targeted, and the associated technical challenge, such as spectrum sensing, is studied. The matter is discussed from the point-of-view of European Commission Security initiative funded Euler project, where WiMAX based interoperable backbone networking waveform is designed, implemented and demonstrated in SDR platforms.

Keywords: Public safety communications, flexible spectrum use, spectrum sensing, software defined radio.

1.0 INTRODUCTION

Wireless public safety network are used by emergency services organizations, such as police, fire & rescue staff and emergency medical services, in order to prevent or respond to incidents that harm or endanger persons or property. Public safety and security (PSS) communications involves the unique application of a set of principles, a combination of technologies, and integration of processes to provide assured communications support for deployed emergency responders.

The following core concepts [1] form the basis of fundamental requirements for providers and users of PSS communications systems:

- *Operability;* The fundamental concept that communications are always able to support the emergency responder.
- *Interoperability;* Stems from the previous concept of operability and refers to the ability of diverse or disparate systems and organizations to operate with each other.
- *Reliability;* A reflection of the assuredness of the operability of the communications systems and the ability to transfer information between end users.
- *Resiliency;* Refers to the ability of operable systems to recover from mishap, change, misfortune, or variation in mission or operating requirements.

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14. ABSTRACT <p>Public safety and security (PSS) communications involve a unique application of a set of principles, a combination of technologies, and integration of processes to provide assured communications support for deployed emergency responders. Among other things, interoperability, reliability and scalability are key requirements for such systems. This paper discusses possible alternatives to enhance PSS communication network capabilities by implementing dynamic spectrum access. Possibilities for dynamically acquiring additional spectrum for PSS systems are discussed. A set of techniques introduced in the cognitive radio domain is discussed and their potential value in the PSS context is evaluated. The issue of using free spectrum spaces is particularly targeted, and the associated technical challenge, such as spectrum sensing, is studied. The matter is discussed from the point-of-view of European Commission Security initiative funded Euler project, where WiMAX based interoperable backbone networking waveform is designed, implemented and demonstrated in SDR platforms.</p>					
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- *Redundancy*; Refers to the resiliency of communications systems that is achieved by alternative means or systems.
- *Scalability*; Refers to the ability of operable systems to respond to change and growth in interoperable communications requirements.
- *Security*; Ensures end-to-end control and continuity as information moves across networks and devices.
- *Efficiency*; Refers to the ability of the system to effectively use resources.
- *Interdependence*; Reflects interdependencies between the communications sector and the national infrastructure.

Public safety workers are increasingly being equipped with wireless laptops, handheld computers, and mobile video cameras to improve their efficiency, visibility, and ability to instantly collaborate with central command, coworkers and other agencies. The missions of the PSS communication networks are to provide to the related forces all the services and applications that can leverage their efficiency to the maximum. Essential features for modern services and applications include:

- Effective PMR (Professional Mobile Radio) Services to provide reliable and secure communications
- High data rate connections supporting any kind of broadband application
- Dual way real time video transfer (upstream and downstream)
- Enhanced services and applications dedicated to public safety forces
- Secured dispatching and recording solution
- Powerful network management with user friendly GUI

The need to access and share this vital new flow of data and images is leading to a critical requirement for a new kind of network: broadband wireless networks using high date rate waveform, such as WiMax. These networks can maintain connections with highly mobile workers, deliver large amounts of low-cost bandwidth with extremely high reliability, and support real-time video, voice and data.

However, the current public safety networks offer mainly voice services and low bit-rate data transfer services through core PMR technology such as TETRA [2], which is currently widely adopted in Europe. Current technologies may provide wideband data services as an evolutionary step but so far they have not gained much success due to severe scalability problems that are intimately related to the limited bandwidth capabilities compared to the requirements.

Alternative way to provide wideband data services for public safety operations is to rely on heterogeneous technologies mainly coming from commercial networks (3G networks, WLANs, WMANs etc.). Major problem is that the infrastructures required by these commercial networks cannot be expected to survive any major catastrophes, such as earthquakes or floods. Therefore they do not fulfill the operability and reliability requirements and are not able to reach an equivalent level of service than the voice services offered through the PMR dedicated technologies. As a result, a combination of broadband capacity and PMR specific features fulfilling the essential requirements is now expected by public safety networks users.

In case of crisis situation, PMR networks must be able to rapidly deploy a networking node based on single radio cell coverage. This single radio cell might operate either in stand-alone mode with full PMR services availability for the people under the cell coverage or as a complementary node to an existing PMR infrastructure network. Highly unpredictable scenarios and operational conditions make preparations

for such emergency services difficult and therefore techniques which are able to provide self-adaptation features of the wireless services on site of the event should be considered. Moreover, PSS broadband networks, whatever the technology selected to support broadband aspects must be interoperable with existing PMR networks, in particular the Tetra technology.

The EU Commission Security initiative funded EULER (European software defined radio for wireless in joint security operations) project [3] proposes a novel architecture for PSS communications based on utilization of SDR (Software Defined Radio) technology [4]. It also addresses the self-management issues as well as the dynamic spectrum management in crisis operations. This paper addresses the problem of mapping and utilizing the radio spectrum in dynamic and autonomous manner for PSS communication services.

2.0 PSS SPECTRUM ISSUES

2.1 Spectrum Allocation Issues

Across the European Union, most public safety national agencies have invested in dedicated narrowband digital mobile networks for voice centric and limited data communications. Spectrum used for those networks was allocated in 1994. In Europe, 380-400 MHz frequencies are often used for (narrowband) public safety and the most common type of network is TETRA as discussed earlier. However, similar approach is needed for broadband data for example for video transmission in rescue operations [5]. A commonly accepted European wide spectrum agreement for enhanced PSS communications would be extremely useful for public safety. Common standard would lower the prices, would be more future proof, and would enable cross border cooperation [6].

Additional spectrum could be allocated and dedicated for PSS e.g. as a result of freeing up radio spectrum from the “digital dividend” [7] (i.e. the spectrum of the analog TV-bands that are left vacant as a result of European-wide adoption of Digital TV-transmission technology). This adoption should be complete around 2012. Organizations with interest to enhance the public safety communication, such as PSC-Europe, are heavily claiming that it is essential for Public Safety services to have access to appropriate spectrum sufficient to meet their evolving operational needs which will include video and other picture applications in all parts of the European territory [8]. However, since this additional spectrum has extremely high economical value, it is uncertain whether consensus of allocating part of it to PSS can be assumed. It should be noted that the radio spectrum belongs to Member States, and thus cross-border coordination and common radio spectrum policy in EU would facilitate a most efficient utilization in PSS (as well as in any other wireless services).

Availability of more spectrum (especially below 1 GHz) may not improve soon. This may motivate the use of cognitive radio [9], [10] techniques for finding resources for broadband communication (for voice legacy allocations could be still used) or for a backbone network. Even if the strict licensing of bands for PSS is not achieved, the cognitive radio technologies may allow a novel approach where parts of the spectrum are allocated for PSS as a primary user of the spectrum. According to cognitive radio principle, if the primary user (i.e. PSS) is not using the spectrum, the secondary systems, such as mobile broadband services, may utilize the spectrum for their own usage. The main requirement is that the secondary users vacate the spectrum when primary user is using it.

2.2 Dynamic Frequency Access (DSA)

Dynamic Frequency Selection (DFS) describes the technique where prior to transmitting, a radio attempts to detect the presence of other, possibly licensed, radios and avoid operating on frequencies that could cause interference with other radios or other systems. DFS can be defined as a general term used to

describe mitigation techniques that allow, amongst others, detection and avoidance of co-channel interference with other radios in the same system or with respect to other systems. In current paradigm of cognitive radios, the DFS is extended to include a scenario where the radio (Cognitive Radio, CR) actively seeks free spectrum bands in order to enhance the services by having access to higher share of the spectrum bandwidth. This process could be called Dynamic Spectrum Access (DSA).

To support the DSA, modern radios moreover posses adaptive bandwidth control, where the CR is able to expand or contract its operating emission bandwidth to avoid interfering with other radios. Essential feature is also transmit power control, where CR using feedback or some other means uses the least practical amount of transmitted power to minimize interference. Transmit power control may also involve the reception of interference information from other co-channel systems. Finally, if the CRs are equipped with directional and steerable antennas, the radiation patterns can be controlled and thus interference can be further reduced. Naturally, controllable radio patterns can be combined with awareness of the directions of desired receivers and the directions of potential victims of interference to improve performance (see e.g. [11], published in the proceedings of this conference).

2.3 Temporal Adoption of Civilian Bands

To start the discussion of possible DSA methods to access additional spectrum for emergency services let us first consider two scenarios, where civilian bands are temporarily adopted for public safety services:

- In scenario 1), there is big disaster such as major flood or earthquake, but the communication infrastructure is not down. In this case the cellular bands and ISM bands will be filled with traffic (emergency calls, text messages etc.), so that dynamic spectrum access using these bands may not be possible. In this case, some kind of authenticated signaling from the PSS users could be transmitted so that the commercial operators temporarily allocate some of their spectrum for the PSS users in a particular geographical area (preferably as a primary user).
- In scenario 2), the commercial communications infrastructure (or part of it) is down due to, for example, big earthquake. In this case cognitive radio techniques could be used for finding channels that the remaining private transmissions are not using. Both licensed and licence-exempt (ISM) bands are possible to use. In ISM bands there are no primary users, so that the existing users theoretically do not need to be protected. However, it is not good idea to use ISM bands if there are already several other users generating interference.

In scenario 2), one potential problem is how to locate the free unoccupied bands (so called “white spaces”) so that they could be used by public safety. One answer is to use cognitive techniques such as spectrum sensing [12]. Note that current policies set by regulators do not allow this type of dynamic spectrum access. However, in the future it could be applied for a better use of spectrum resource. Essentially, in this case PSS communication system is considered as a secondary user of the spectrum.

The above discussion assumes that the PSS would be the secondary user of the spectrum or that it can temporarily by request obtain primary user status in some bands. It is also possible that PSS is always the primary user. For example, in the US, FCC has allocated the 700 MHz band jointly to public safety and private sector. The private sector has interruptible secondary access to the spectrum, provided that the primary user (public safety) is not present. Shared infrastructure between public safety and private sector will lead to higher cost effectiveness. PSS being the primary user would help a lot in scenario 1).

2.4 Locating Free Spectrum by Spectrum Sensing

The strategies for additional spectrum described previously partly rely on the assumption that the secondary users of the spectrum are able to sense spectrum and, in particular, vacate the bands when primary user becomes present.

There are several ways to implement spectrum sensing [12]. The most common and simplest approach is to use energy detector. An energy detector simply measures the signal energy, denoted here with V , in the currently studied channel and compares it to a threshold. If the threshold is exceeded, then we declare that a primary user is present and the channel cannot be used by secondary users. If the threshold is not exceeded, then we declare that the channel is free (unoccupied).

No matter how it is done, spectrum sensing can never be error-free process. If we falsely think that a band is unoccupied when in fact it is occupied by primary user(s) (miss detection), then we cause unwanted interference to the primary user. The regulator may set some upper limit for the probability of misdetection that must be satisfied by all cognitive radios. Sometimes sensing is difficult due to low signal-to-noise ratio (SNR) due to shadowing and fading. In order to improve energy detector performance, more sophisticated techniques exist, such as solutions based on radio signal cyclo-stationarity property [13], which enables to detect a signal at lower SNR. Another possible way consists in making cooperative sensing utilizing space diversity. Another probability related to cognitive radios is the probability of false alarm, which is the probability that we think that the studied frequency band is occupied when in fact it is free (primary signal absent). High false alarm limits the spectrum utilization by secondary radios. Unfortunately, there is a trade off between false alarm and misdetection probabilities, i.e., if we reduce false alarm, then (for the same parameters) the misdetection probability will be increased.

There are several ways to set the detection threshold. The easiest approach is to control the false alarm probability, as this requires only knowing the noise variance (of internal thermal noise + possibly external noise) when primary user is not present. For example, typically false alarms such as 10% and 1% are used. In practice, the noise variance cannot be perfectly estimated. This may, in some cases, lead to much reduced detection performance. Constant false alarm rate (CFAR) techniques familiar from radar may be applied to reduce this loss. Another alternative is to set the threshold so that the probability of detecting the presence of the primary user of certain strength has some required value, such as 90%, 95%, or 99%.

2.5 Cooperative Spectrum Sensing

In (distributed) cooperative sensing, several close-by terminals form a coalition with one node being selected (perhaps the most powerful terminal with high battery level) as the cluster head. The coalition members make a local decision (primary present or not) and send it to the cluster head (fusion center). The cluster head will then use some rule such as the “MAJORITY” rule to make the final global detection decision. This type of cooperation can significantly increase the probability of detecting the presence of the primary user, especially when some of the terminals are shadowed.

2.6 Spectrum Access by Spectrum Database

As discussed above, spectrum sensing can be somewhat unreliable, and some doubts whether spectrum sensing alone can really be utilized in dynamic spectrum access have been put forward [14]. Alternative way although not as flexible and dynamic would be to rely on centrally managed spectrum usage database and associated spectrum broker. The idea is that all relevant information about the regional spectrum usage is being stored and frequently updated in centrally located database. The information about possible temporarily available white spaces is then either broadcasted or delivered by request to any actor, who wishes to setup a new service or utilize more bandwidth to provide better service.

There are, however, some unsolved problems in this scenario. First of all, commonly known dedicated channel is needed, on which the spectrum availability information could be accessed/delivered. In relation to cognitive radio research, this type of common control channel is often referred to as Cognitive Pilot Channel (CPC) [15][16]. (Note that in this text we treat CPC as way to access the spectrum database information). CPC is proposed as a more reliable, cost-efficient and effective way of implementing the dynamic spectrum access [17]. By definition, the purpose of CPC is to broadcast/provide data allowing a

terminal/network to acquire knowledge of the available radio access networks in the surroundings, without having to sense the spectrum.

Other problems that need to be solved in the spectrum database usage are related to the possible location and manager of the database. Four different models can be listed:

- 1) If *commercial operator(s) manage the database*, the CPC could be implemented as an in-band solution (i.e. utilizing only the spectrum allocated to those particular operators). This model invokes the question, whether the commercial operator is willing to sacrifice its own revenue by allowing even temporary access to others users of the spectrum.
- 2) Alternative solution is that the spectrum database is *government managed* and therefore the CPC is implemented as out-band. This solution naturally requires that a dedicated channel is reserved outside the already reserved spectrum. If all commercial operators in a particular geographical area can be persuaded to provide their timely spectrum allocation information to the unbiased spectrum broker, a fair dynamic allocation of spectrum could in principle be achieved.
- 3) Instead of government managed solution, a new type of *commercial CPC provider spectrum broker*, could exist. This broker would collect spectrum usage information of all local networks, combine it, and provide the spectrum access information as a service for third parties. This model invokes complex models for various spectrum commerce alternatives.
- 4) Finally, a *hybrid model* is possible where a simple out-band CPC exist for advertising different operators in the area, combined with in-band operator controlled CPC for more detailed spectrum allocation information.

From the point-of-view of PSS communications the alternative 2) seems most promising, especially if it can be combined with method to decrease the spectrum usage of commercial operators in the time of crisis, i.e. reserving more spectrum for PSS (see scenario 1) in section 2.3 above). But the spectrum database information requires additional agreement of standard signaling structure for requesting/delivering/broadcasting the spectrum information. Yet another question is related to possible timeliness of the information in the database.

3.0 PUBLIC SAFETY INTEROPERABILITY & EULER

Public safety communications is nowadays characterized by a patchwork of separate, often incompatible systems and PMRs with varying capabilities in communicating between and among systems. Instead of replacing all of these separate systems with new solutions, another way to make the communication more efficient and interoperable is to *integrate the separate systems by a common wireless backbone network*. The connection of PMRs' legacy networks (IP based interfaces) with a common high data rate backbone has high importance in practical situations and is currently being considered in the Euler project.

The key technical issues addressed in Euler project include:

- The design of EWF (Euler WaveForm). EWF will primarily support a high data rate backbone network interconnecting separate wireless PMR systems. One possible candidate for waveform for such a public safety backbone is WiMAX. OFDMA-based WiMAX is field-proven. Also, WiMAX can be made to operate with various frequency bands, both licensed and unlicensed and thus cognitive radio techniques as described above could be used. In Euler a waveform based on WiMAX (802.16e) [18] will be developed.
- Operational requirements for the novel EWF are obtained from a dedicated group of end-users involved directly with the project.
- Collaborative waveform implementation to different Software Defined Radio based platforms.

- Integrated demonstration will be arranged towards the end of the project to illustrate a) the benefits of using SDR-technology in public safety communications and b) to highlight the interoperability provided by a common backbone based network solution.

4.0 DISCUSSION

WiMAX can operate both in licensed and unlicensed bands. In public safety, using network infrastructure of the licensed operator may not be desirable due to control, reliability, and congestion issues. This could still be considered as complementary solution. This is unless we use the licensed bands as secondary users, however then we would still have the congestion issues (in scenario 1 but not in scenario 2) or we co-exist with the primary user using some mechanism. Also, we could use WiMAX even in the existing public safety bands or bands allocated just for it [19].

On the other hand, using license-exempts bands PSS can get an “own” network. However, this may lead to performance degradation. Specifically, it has been shown that WiMAX has a reduced performance when coexisting with 802.11a in license-exempt (shared) frequency bands [20]. Currently, 802.16h is working on Improved Coexistence Mechanisms for License-Exempt Operation [21]. They are also proposing improved co-existence with 802.11. In case of secondary operation, in 802.16h, synchronized silence intervals can be applied for getting the required radio silence for cognitive detection of primary signals such as TV signals or wireless microphones.

To summarize, the Euler backbone network could operate with:

- a) Licensed bands temporarily or permanently allocated to it so that Euler would be the primary user (suitable for scenario 1, almost guaranteed performance, but a method to temporarily allocate/request bands to Euler is required),
- b) Licensed bands owned by another (primary) user, so that Euler would be the secondary users (suitable for scenario 2),
- c) Licensed bands shared between Euler and another network(s) with some kind of sharing mechanism for the band (with Euler having priority),
- d) License-exempt bands requiring no license (but with interference from other users of the same spectrum) (suitable for scenario 2).

The SDR Forum Public Safety SIG has explored some of these issues in greater detail and has published a document describing improvements in interoperability [22].

5.0 SUMMARY

Radios that are aware of their spectral environment provide benefits by accessing previously unused, unavailable, or forbidden spectrum. Spectral awareness may enable the use of this spectrum without causing interference to the radios operating in the spectrum. Radio spectrum is a scarce resource: there is little spectrum available for dedicated allocation without displacing current users. Interest is high to find ways to use spectrum more efficiently. Utilization levels vary widely between services and geographic areas, with some having substantial amounts of “white space”, or unused channel-minutes. Radios capable of exploiting unused or lightly used spectrum without introducing interference will improve efficiency of spectrum utilization.

This paper has discussed possible alternatives to implement dynamic spectrum access in public safety and security communication framework. The matter is discussed from the point-of-view of Euler project, where WiMAX based interoperable backbone networking waveform is designed, implemented and demonstrated in SDR platforms.

This paper overviewed a set of techniques introduced in the cognitive radio domain in order to show their potential interest in the PSS context. The issue of using free spectrum spaces was particularly targeted, and the associated technical challenges, such as spectrum sensing, studied.

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